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THE QUANTITATIVE USE OF ECHO SOUNDERS

- INTRODUCTORY NOTES

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PREPARATION OF THIS DOCUMENT

This document, prepared by Mr. R.E. Craig, Senior Scientist, FAO Fishery Research and Development Project, Peru, is issued within the FAO Fisheries Circular series mainly to meet the needs of FAO's training activities initially in English at the FAO/NORAD Training Centre in Acoustic Methods for Fish Detection and Abundance Estimation to be held in Cochin, India from 5-23 November 1973 but also in Spanish for the proposed FAO/NORAD Latin American Regional Acoustic Research Centre to be based in Peru from 1974 to 1976.

This Circular supplements the Manual of Methods for Fisheries Resource Survey and Appraisal, Part 2, "The use of acoustic instruments for fish detection and abundance estimation", FAO Man.Fish.Sci., (5) and gives more detailed instruction in the theory and use of echo integration. As this whole technological field is rapidly expanding, it is expected that updating may be required but the basic concepts will remain the same. It is felt that the descriptive units to be used in this type of work, particularly for intensity (see p.13 need to be reconsidered. This Circular is in no way contradictory to the guidelines already laid out in the above manual but is rather intended as a stimulant to an overall consideration of such factors before the acoustic research in fisheries develops to such a stage that it may be too late or very difficult to effect any changes in nomenclature or definition.

Because of the basic principles involved it was decided to disseminate this document as an FAO Fisheries Circular in order to give the widest possible circulation to the basic understanding of echo-integration techniques.

The views expressed in this Circular are those of the author and not necessarily of the Food and Agriculture Organization of the United Nations. At this stage, the study is presented in a preliminary form. All readers are kindly invited to send any comments or criticisms to the Marine Biology and Environment Branch, Fishery Resources Division, FAO.

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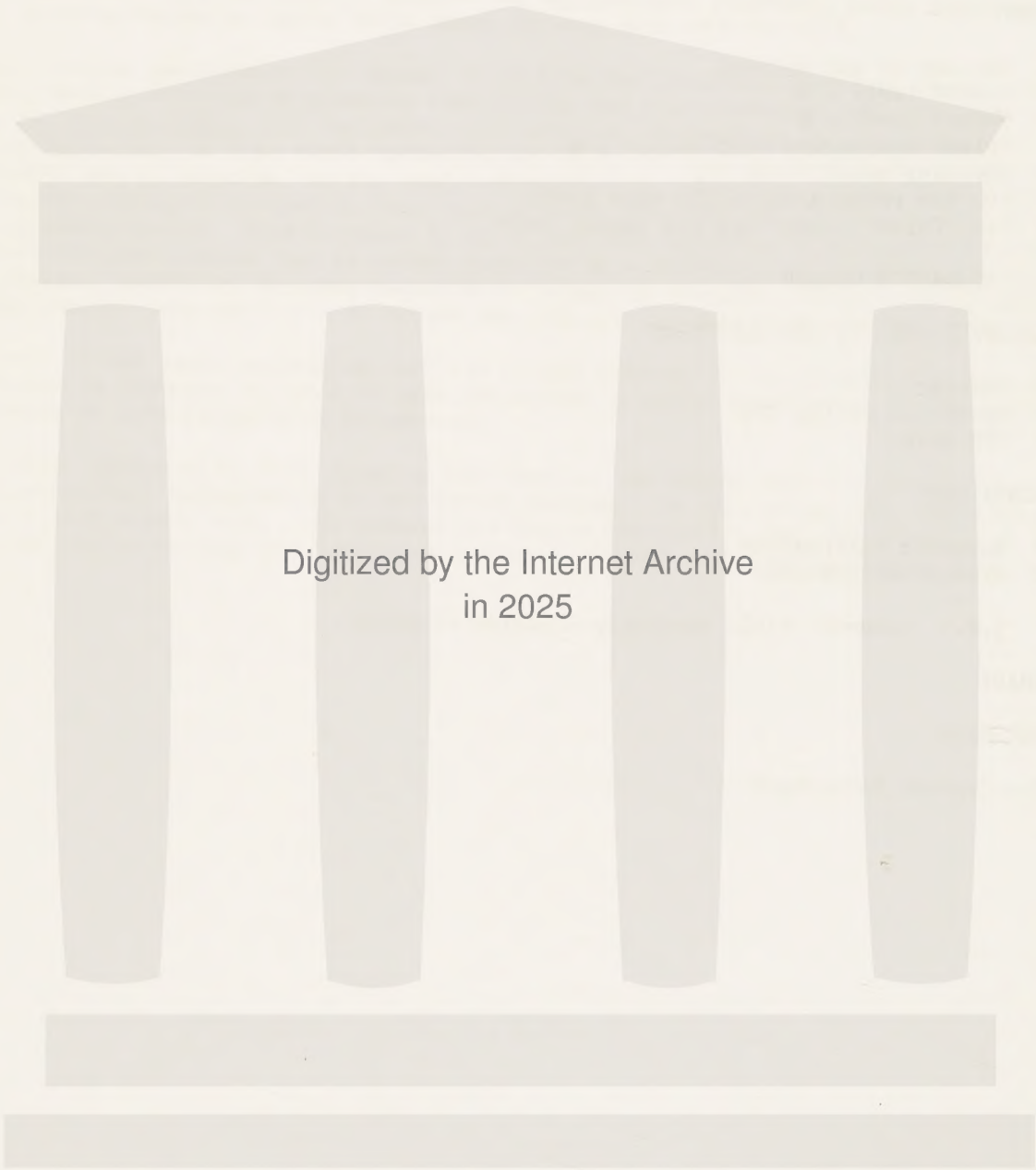

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1. INTRODUCTION

Fish studies by acoustic methods demand the following:

(a) Biologists and their knowledge of the fish

(b) Engineers and their knowledge of the equipment

(c) An understanding of the special theory of this topic.

This paper is a contribution to the last item, limited to what is necessary for the use of an integrator. It also provides an introduction to the general theory.

The use of acoustic methods in fisheries research has been described in a recent FAO Manual (Forbes and Nakken, 1973). However, for "beginners" in this relatively new technological field it was felt that some more detailed introductory advice was necessary. The example taken to illustrate this Circular is the SIMRAD scientific sounder since this is the most popular model available on the commercial market which has (a) Time Varied Gain function (TVG), i.e., compensation for the two-way transmission loss of power of the acoustic signal in water, and (b) the capability to add integrators and other units to the basic module (Gerhardsen et al., 1968?). The use of the trade name SIMRAD and the description of this equipment does not imply any endorsement by FAO of this particular product.

2. THEORY

2.1 The use of the decibel

The decibel is normally used to compare levels of power. If there is a signal of power p_1 and a smaller one p_2 we can say that the difference between the two is x dB where

$$x = 10 \log p_1/p_2 \qquad \ldots\ldots\ldots (1)$$

The magnitude of the decibel can be appreciated from Figure 1 in which each vertical line represents a power 1 dB greater than that on its left.

Signals are often compared by reference to their voltage or amplitude. Since the power of a signal depends on the square of the voltage, the difference in decibels can be written

$$x = 20 \log v_1/v_2$$

This relation is shown in Figure 2. A change in level by 1 dB can be easily detected on an oscilloscope.

To appreciate this concept of the decibel it is useful to scan a table of anti-logarithms. Since from equation (1)

$$x/10 = \log p_1/p_2$$

if we enter the table for values of x/10 we shall be able to read off the values of p_1/p_2. Opposite .10 appears the figure 1.259 which represents the power ratio for 1 dB. Opposite .20 appears the figure 1.588 and opposite .30 is 1.995. This latter represents the power ratio for 3 dB and is conventionally considered as 2.0 ; thus a change of 3 decibels is equivalent to 'doubling the power'.

In the table of anti-logarithms can also be found the voltage ratios. Opposite .05 appears the figure 1.122 which is the voltage ratio for 1 dB, and opposite .15 is the figure 1.413 which is the voltage ratio for 3 dB, that is to say for doubling the power. Obviously + 10 dB represents an increase in the power by a factor of 10 and + 20 dB represents an increase of power by a factor of 100 or an increase in the voltage by a factor of 10.

In this manual script letters will be used to represent quantities in normal units, for example $\mathcal{p}$ in watts, and printed letters represent the same quantities in decibels, for example p in dB ref 1 watt. Thus we may write

$$p = 10 \log \mathcal{p}$$

and similarly for other quantities.

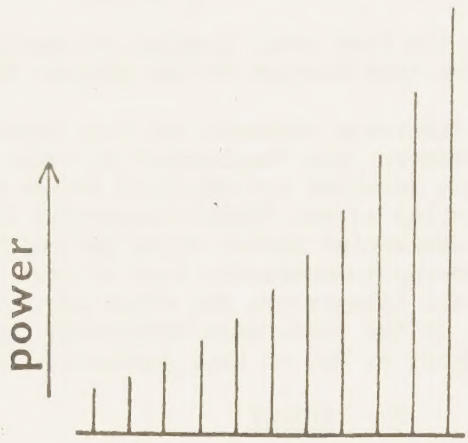

Figure 1. Illustrating the decibel unit. Each vertical line represents a power one decibel above that on its left.

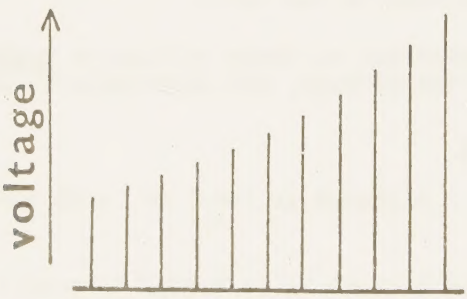

Figure 2. Illustrating the decibel unit. Each vertical line represents a voltage one decibel above that on its left.

Since decibels will be used to indicate power, it is convenient to employ the same units for certain other factors. A system of units and symbols is set out in Table I.

2.2 Source level : S (the measure of effectiveness of an acoustic source)

An electric signal applied to the transducer produces an acoustic field in the water which is propagated at a velocity of 1 500 metres per second, being slightly more or slightly less according to the water quality. Thus if a target be situated at a range of 750 metres from the transducer, the echo will return in 1 second. The intensity of the acoustic field is expressed as the number of decibels above or below 1 watt per square metre. The source level in a particular direction is defined as S if in that direction, at a range of 1 metre, the acoustic field intensity is S dB ref 1 watt per square metre. In the same way can be defined the axial source level S_odB, measured on the beam axis.

The source level can be more appropriately defined mathematically as a level in decibels ref 1 watt per steradian (per unit of solid angle). The source level in a particular direction can be expressed as

$$S = S_o + d$$

where d represents a directional factor. Thus d = 0 dB on the beam axis and takes negative values for all other directions.

2.3 Target level : T (more commonly referred to as 'target strength')

The acoustic energy is dispersed by the target in all directions. However in echo sounding the only relevant energy is that returned by the target in the direction of the transducer. The target can be considered as a secondary source stimulated by the incident field. If the target behaves as a source of level T dB when the incident field intensity is 0 dB, it is said to have a target level of T dB. A big hake for example might have a target level of - 25 dB and a big anchoveta a target level of - 50 dB. (More information is needed about the target levels of different species, at the various frequencies in use.)

2.4 Volume scattering coefficient : s (the measure of biomass)

This is an important parameter. A value of, say, s = - 40 dB indicates that the echo level from a region will be the same as if there were one single target of target level T′ in each cubic metre.

If a region of volume $\mathcal{V}$ has a volume scattering coefficient s then the target level of the region is

$$T = s + V \qquad \ldots\ldots\ldots (2)$$

Further, if there were n targets per cubic metre, each of target level T′ then

$$s = T' + 10 \log n \qquad \ldots\ldots\ldots (3)$$

and so the target level of the volume $\mathcal{V}$ can be written

$$T = T' + 10 \log n + V$$

(remembering that $V = 10 \log \mathcal{V}$ and so on for other quantities)

2.5 Receiver sensitivity : K

Consider an acoustic field of intensity I_r reaching the transducer from some specified direction, and suppose that this produces a calibrated receiver output of C dB ref 1 watt. The receiver sensitivity for this direction is defined by K where

$$C = K + I_r$$

TABLE I

LIST OF SYMBOLS AND UNITS

$\mathcal{R}$	range metres	
$\mathcal{I}$	acoustic intensity watts m^{-2}	10 log $\mathcal{I}$ = I
$\mathcal{S}$	source level watts per steradian	10 log $\mathcal{S}$ = S
$\mathcal{K}$	receive sensitivity m^2	10 log $\mathcal{K}$ = K
$\mathcal{d}$	transducer directional factor	10 log $\mathcal{d}$ = d
$\mathcal{C}$	calibrated output signal watts	10 log $\mathcal{C}$ = C
$\mathcal{A}$	solid angle for integration steradians	10 log $\mathcal{A}$ = A
$\mathcal{T}$	target level m^2 per steradian	10 log $\mathcal{T}$ = T
$\mathcal{s}$	volume scattering coefficient m^{-1} per steradian	10 log $\mathcal{s}$ = s
$\mathcal{s}_a$	area scattering coefficient per steradian	10 log $\mathcal{s}_a$ = s_a
$\mathcal{V}$	pulse volume m^3	10 log $\mathcal{V}$ = V
$\mathcal{L}$	0.75 t metres	10 log $\mathcal{L}$ = L
t	pulse duration in milliseconds	
$\mathcal{W}$	biomass per unit volume kg m^{-3}	
$\mathcal{W}_a$	biomass per unit area kg m^{-2}	
$\mathcal{g}_i$	constants	10 log $\mathcal{g}_i$ = g_i
$\mathcal{E}$	integrator output volts (representing watt seconds)	
m	number of transmissions in a given distance	
c	calibrated output signal in volts	

If the same transducer is used for reception and transmission, the directional factor is the same for both functions, and an axial receiver sensitivity K_o can be similarly defined, where

$$K = K_o + d$$

A target of level T at a range of 1 metre in some specified direction will give rise to a calibrated output signal

$$C = S + K + T$$

$$= S_o + K_o + 2d + T$$

The dependence of the factor d on direction raises mathematical problems which are dealt with in more detailed papers. The operator can avoid these problems by reference to the manufacturer's transducer data.

It should be stressed that it is not essential to know the level of the calibrated output signal in watts, because all the necessary calculations can be made by adopting throughout an arbitrary reference level, for example a signal of 1 volt peak. This is normal practice.

Figure 3. Illustrating the fact that the acoustic power of the transmitter is spread over a greater area at a greater range. The acoustic intensity varies inversely with the square of the range.

2.6 How the range affects the echo level

Up to this point only targets at a range of 1 metre have been considered. We now have to generalize, and look at the situation where the target is at a range R. It will be clear from Figure 3 that the transmitted energy is spread over an area which is greater by a factor R^2. Thus the acoustic intensity at the target is correspondingly reduced to

$$\mathcal{I}_t = \mathcal{S}/R^2$$

or in terms of dB $I_t = S - 20 \log$

so the target will act as an apparent source of level

$$S' = T + S - 20 \log R$$

and the intensity of the acoustic field returning to the transducer is

$$I_r = S' - 20 \log R$$

or

$$I_r = T + S - 40 \log R \qquad \ldots\ldots\ldots (4)$$

2.7 The "Pulse Volume" and its target level

At any given instant, all the targets contributing to the echo lie within a region of a spherical shell, as will be clear from Figure 4.

From the manufacturers' data can be found the solid angle A appropriate for integration, and the pulse duration. We need the value of L which is

1/2 (pulse duration x sound velocity). From the known velocity,

$$L = 0.75t$$

where is the pulse duration in milliseconds which is marked on the instrument or can be measured with the oscilloscope.

The Pulse Volume V has a value

$$V = A R^2 L$$

or

$$V = A + L + 20 \log R$$

since L is small compared to R. The target level of the Pulse Volume in accordance with equation (1) is

$$T = s + V$$

$$= A + L + s + 20 \log R$$

and substituting in equation (4) we obtain the acoustic field intensity returning to the transducer as

$$I_r = S + A + L + s - 20 \log R$$

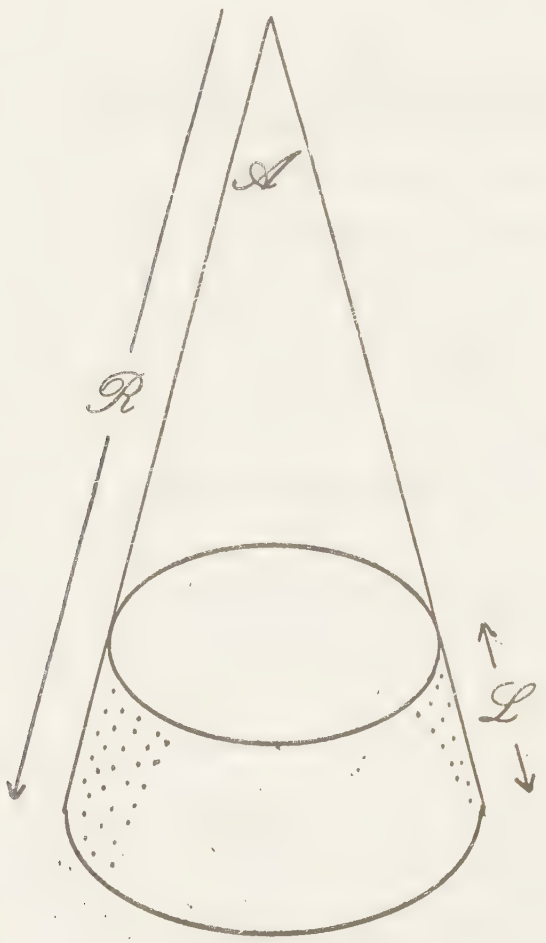

Figure 4. Illustrating the concept of pulse volume, $V = A R^2 L$ which is important for fish integration calculations. The echo intensity at any instant is the resultant from all targets within the pulse volume.

Because of the way in which the angle A is derived, we can assume that the axial source level S_o and the axial sensitivity K_o apply within A and that $\beta = \kappa = 0$ outside this angle. The calibrated output signal resulting from this value of I_r is

$$C = S_o + A + L + s - 20 \log R + K_o \quad \ldots\ldots\ldots (5)$$

Because we must have a simple relationship between C and s the system is designed with TVG, that is to say the sensitivity varies in accordance with the range. If a '20 log R' TVG is selected the system sensitivity will take the form $K_o + 20 \log R$, where K_o is the sensitivity for a target at 1 metre range.

(A small additional correction is described later to take account of attenuation.) Provided we select this '20 log R' TVG, equation (5) can be rewritten in the form

$$C = S_o + A + L + s + K_o \qquad \ldots\ldots\ldots (5a)$$

$$s = C - S_o - A - L - K_o$$

We may note that: C is measured on the oscilloscope

S_o and K_o are obtained from calibration

A and L are manufacturers' data

At this stage it can be seen that the echo sounder can be used to obtain the value of s which gives information about fish, for it will be remembered that

$$s = T' + 10 \log n$$

where T' is the target level of each fish, and n is the number of fish per cubic metre.

3. THE INTEGRATION METHOD

It has been established in section 1 that :

$$s = C - S_o - A - L - K_o$$

which may be written

$$s = C + g_1 \qquad \ldots\ldots\ldots (6)$$

where $g_1 = -(S_o + A + L + K_o)$ is a determinable constant of the equipment. This equation appears in non-decibel units as :

$$s = g_1 c$$

It has been noted that s depends on the number n of fish (targets) per cubic metre, and on the target level T' of the individuals, thus :

$$s = T' + 10 \log n$$

* The results of many experiments suggest that T' is very approximately proportional to fish weight, and accordingly

$$s = 10 \log W - g_2$$

where g_2 is a quasi-constant for fish at the frequency in use and W is the fish weight (the biomass) per cubic metre. In normal units :

$$W = g_2 s \qquad \ldots\ldots\ldots (7)$$

$$= g_1 g_2 c$$

---

* This paragraph indicates the limitations of the method, dependence on a "quasi-constant"

Given that we accept an arbitrary reference level of 1 volt peak for this relation reduces to

$$W = g_1 g_2 c^2$$

where c represents the peak voltage at the calibrated output. Considering only the echoes from a single transmission, selected between the depth limits R_1 and R_2, obviously we obtain a measure of the biomass per unit of area from the integration between those limits

$$W_a = \int_{R_1}^{R_2} W \, dR$$
$$= g_1 g_2 \int_{R_1}^{R_2} c^2 \, dR$$

The integrator is designed to produce from each transmission an output $\Delta \mathcal{E}$, which is exactly proportional to $\int c^2 dR$; a relation which may formally be expressed by :

$$\int_{R_1}^{R_2} c^2 dR = g_3 \Delta \mathcal{E}$$

and so $$W_a = g_1 g_2 g_3 \Delta \mathcal{E} \qquad \ldots\ldots\ldots (8)$$

or $$W_a = g_4 \Delta \mathcal{E} \qquad \text{where} \qquad g_4 = g_1 g_2 g_3$$

If the ship covers a certain distance, during which occur m transmissions, the integrator output rises to $\mathcal{E}$, which is the sum of the $\Delta \mathcal{E}$. Obviously the mean value of W_a over this distance is obtained from

$$W_a = g_4 \mathcal{E}/m \qquad \ldots\ldots\ldots (9)$$

In the SIMRAD equipment there are two controls which take account of the ship's speed and the recorder depth scale, in order to display a value of the integral per mile. These controls alter the value of the constant g_3 to allow for the number of transmissions which have occurred in 1 nautical mile. It is more direct and more accurate to leave these controls in a standard position during calibration and operation. If the number of transmissions is noted on a counter, or otherwise estimated, equations (8) and (9) can be applied directly to calculate the required value of W_a.

4. CHARACTERISTICS OF THE EQUIPMENT

4.1 General

Though much more detailed knowledge is required by the engineers concerned, the operators have to know enough to be sure the equipment is working correctly, or if it is not, to be able to report faults clearly to the engineers. This basic knowledge will also be of assistance in operating the equipment and in interpreting the results.

'Test/operate' switch

This will be found on the recorder. The circuits involved are as shown in Figure 5.

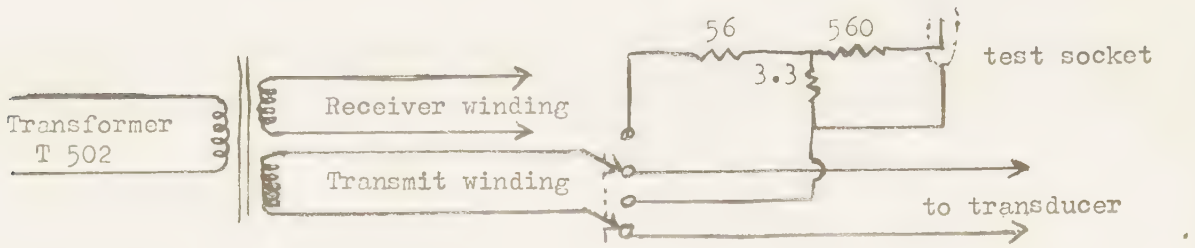

Figure 5. Circuits involved in the sounder

With the switch set to 'Operate' the circuit is as shown above, the transmit winding being connected to the transducer. In the 'test' position the transducer is replaced by the network of resistors.

(a) Set the switch to 'test' and switch on the sounder. The transmit voltage will appear at the test socket, reduced by the factor 3.3/59.3 that is by 1/18. This can be measured on the oscilloscope, and the pulse length checked at the same time. This check is to disclose any change in the transmit voltage since the calibration. For example, if the voltage decreased by 8%, then the source level S would have changed by 20 log 0.92 that is by - 0.72 decibels.

(b) With the equipment set as above, but no transmission (e.g., switch to 'external transmitter') a test signal can be injected at the test socket to measure the receiver amplification. The test signal is reduced in amplitude by the network by a factor of 3.3/563.3, that is to say by 45 dB.

The most obvious way to make the measurements is to connect the signal generator output, in parallel, to the 'B' input of the oscilloscope, to the electronic counter, and to the input of the attenuator. Then connect the attenuator output to the 'test socket' aforementioned and the calibrated output of the sounder to input 'A' of the oscilloscope. The frequency can be adjusted to 38 KHz or 120 KHz by the counter, and the signal generator output to 1 volt peak using the oscilloscope. Then the virtual level of amplification can be obtained by turning the attenuator until the calibrated output is also 1 volt peak, and noting the number of decibels.

The amplification corresponding to any given range can be measured as discussed later, or the maximum amplification measured by switching to 'external recorder'. This stops the recorder and cuts out the Time Varied Gain.

4.2 Operation of the TVG

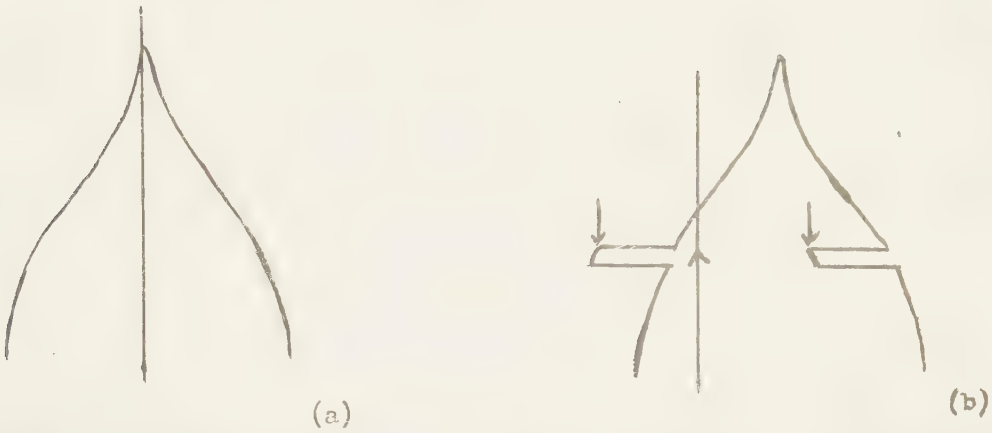

Figure 6. TVG controlled signal output from an echo sounder (a) without, and (b) with integration range gate superimposed

If the equipment is run without transmission, and a constant signal is injected, the calibrated output appears as in (a). To measure the amplitude at a selected depth, the best method is to put the 'interval' signal from the integrator to input 'B' of the 'scope. If the appropriate depth interval is set on the depth selectors of the integrator and the 'scope set to 'add', then the required depth slice appears offset on the screen as shown in (b).

The amplitude corresponding to the selected depth can then be measured, being the distance between the arrows. (Since we have now used input 'B' for another purpose, it is essential to check from time to time that the signal generator output has remained constant.)

Thus the level of amplification can be checked, for example K'_{10} at 10 metres, K'_{50} at 50 metres and so on. We reserve the symbol K' for the amplification at 1 metre, to correspond to the definition of the more fundamental quantities K and K_o.

It is most important to appreciate that the TVG does not operate correctly for depths less than 3 metres. Therefore the key parameters K', K and K_o always have to be obtained by extrapolation. For example $K' = K'_{10} - 20$ dB. Be clear about this so that you can make correct use of these parameters, and of the equations in sections (1) and (2) which depend on them.

4.3 TVG data

The required variation of sensitivity with range is :

$$\text{sensitivity} = K_o + 20 \log \mathcal{R}$$

and therefore the variation of virtual amplification with range is :

$$\text{amplification} = K' + 20 \log \mathcal{R}$$

This expression does not take into account the attenuation α which is frequency dependent. The corrected expression is :

$$\text{amplification} = K' + 20 \log \mathcal{R} + 2 \alpha \mathcal{R}$$

where the value of α is 0.007 dB per metre at 38 KHz and 0.02 dB per metre at 120 KHz. So the amplification must vary with the range as follows :

	38 KHz	120 KHz
1 metre	K′	K′
5 metres	K′ + 14 dB	K′ + 14 dB
10 metres	" + 20 dB	" + 20 dB
20 metres	" + 26 dB	" + 27 dB
50 metres	" + 35 dB	" + 36 dB
100 metres	" + 41 dB	" + 44 dB
200 metres	" + 49 dB	
500 metres	" + 61 dB	

It is worth remarking that K′ for the 120 KHz machine is about 15 dB higher than for the 38 KHz machine. This arises because the EK 120 sounder is designed for quantitative use only to a depth of 100 metres.

The electrical checks described in this section are useful to guard against the effects of changes in the equipment constants. They are straightforward, and should be carried out at least once per week during operations.

If the transmit voltage, or the value of K′, is found to vary, due allowance can be made and the results adjusted. However if the variation of sensitivity with range (the TVG) is not correct to the maximum depth of integration, then it will be impossible to correct the results. In this event the value of ℓ depends on the depth, and not purely on the biomass w per unit volume, as the theory requires.

An error of 3 dB in the TVG at a particular depth will produce an error by a factor of 2 in the estimate of w at that depth. It is desirable to keep all errors less than $\pm$ 1 dB.

To complete this list of electrical checks, it is desirable to make sure that the calibrated output voltage v is proportional to the test signal, up to the maximum values of v encountered during operation (e.g., up to v = 4 volts). It should also be confirmed that the slope of the integral is proportional to v^2 up to similar levels of v .

5. CALIBRATION

5.1 Acoustic calibration

Acoustic calibration depends on a calibrated hydrophone to obtain the quantities S_o and K_ρ and hence the constant g_1 of section (2). The data sheet supplied with the hydrophone lists its source level for an applied voltage of 1 volt. It also lists its sensitivity as a receiver.

The hydrophone is first placed at a distance R from the transducer, on the beam axis. A suitable distance would be about 3 metres. The sounder is then switched on. The acoustic intensity at the hydrophone is :

$$I = S_o - 20 \log R$$

By measuring the output voltage from the hydrophone on the oscilloscope, and referring to the hydrophone data sheet, we obtain the value of I and thus of S_o.

To measure K_o a known voltage is applied to the hydrophone, providing a source level, say, of S'. Then the intensity of the acoustic field reaching the transducer is :

$$I_r = S' - 20 \log R$$

That is to say we know the value of I_r. The calibrated output C can then be measured and K_o obtained from the relation :

$$K_o = C - I_r$$

In practice an arbitrary reference level of 1 volt is used for C and reverting to non-decibel units we write :

$$K_a = c^2 / g_r$$

and obtain K_o from $K_o = 10 \log K_a$

It is assumed that the recorder has continued to operate during this test <u>without transmission</u>. As explained in section (3) we have to obtain K_a and K_o by extrapolation, having noted the values, e.g., for 100 metres, 50 metres and 10 metres on the TVG sweep.

The theory of this method is simple, but the results clearly depend on the calibration of the hydrophone (which is not easy to check) and on the accuracy with which it is positioned on the beam axis.

5.2 Direct calibration

Direct calibration with live fish is a very important operation. A known concentration of fish is positioned across the beam. The resulting value of b is noted which leads to the value of $g_1 g_2$. At the same time the increment per pulse of the integrator output can be noted, which leads directly to the value of $g_1 g_2 g_3$, that is to g_4. The simplest arrangement in principle is to select a depth interval of 1 metre for the integration. In this case obviously $W = W_a$.

This operation also poses no theoretical problems. However it <u>does</u> involve certain practical compromises. The distance to the centre of the fish concentration must be at least 4 metres, to be within that part of the range scale for which the TVG is correct. The concentration must be established across the whole effective beamwidth, but on the other hand the greater we make the extension of the targets, the more difficult it becomes to ensure their uniformity. It would seem that the dimensions chosen by Johannesson and Robles (1973) are appropriate. Finally, the fish must be lively and in good condition, and they ought to be acclimatized for some hours to the shallow depth in which they will be confined.

5.2.1 Acoustic field intensity - choice of units

At least three different reference levels for intensity exist, and may be encountered in textbooks. In this paper we use 1 watt per square metre. In other sources the reference level may be the intensity corresponding to the unit of sound <u>pressure</u> : 1 microbar (= 1 dyne cm^{-2}) or 1 Pascal (= 1 Newton m^{-2}). Since the field intensity varies with the <u>square</u> of the pressure, these units seem conceptually more difficult. The relations between the units are as follows :

1 watt m^{-2} = + 58 dB ref 1 Pascal = + 78 dB ref 1 microbar

If the units of this paper are accepted, the data sheet for the hydrophone should be amended to show its parameters referred to watts per square metre, and to peak voltages.

6. SUMMARY

FOR ANY SECTION OF THE SHIP'S TRACK THE MEAN VALUE OF THE BIOMASS PER UNIT AREA W_a CAN BE OBTAINED FROM THE EQUATION

$$W_a = g_4 E/m$$

WHERE E IS THE VOLTAGE ACCUMULATED BY THE INTEGRATOR AND m IS THE CORRESPONDING NUMBER OF TRANSMISSIONS.

ADDITIONALLY $g_4 = g_1 g_2 g_3$

WHERE g_1 IS THE ECHO SOUNDER CONSTANT

g_2 IS A QUASI-CONSTANT FOR FISH

AND g_3 IS THE INTEGRATOR CONSTANT

7. REFERENCES

Forbes, S. and O. Nakken, 1972 Manual of methods for fisheries resource survey and appraisal. Part 2. The use of acoustic instruments for fish detection and abundance estimation. FAO Man.Fish.Sci., 5:138 p.

Gerhardsen, T.S. et al., 1968? A systematic approach to the selection of fish detection instruments for fishery research vessels. Oslo, Simrad, 20 p.

Johannesson, K. and A.N. Robles, 1973 Echo surveys of Peruvian anchoveta. Paper presented to the ICES/FAO/ICNAF Symposium on Acoustic Methods in Fisheries Research, Bergen, 19–22 June 1973. Doc.No.54:8 p.

APPENDIX

TYPICAL PARAMETERS

These details refer to the SIMRAD Scientific Sounder at 38 and 120 KHz

	EK 38	EK 120	
S_o	+ 38 dB	+ 41 dB	ref 1 watt per steradian
K_o	+ 18 dB	+ 35 dB	*ref 1 volt watt^{-1} m^2
A	- 18 dB	- 18 dB	
L	- 7 dB	- 7 dB	for pulse duration = 0.3 m sec
g_1	- 31 dB	- 51 dB	
g_2	+ 28 dB	+ 28 dB	(?)
g_1	8×10^{-4}	8×10^{-6}	
g_2	600	600	(?)

for the integrator speed control set to 12 knots and switch to Scale 'A'

g_3	350 (10 dB: x 10)	350 (0 dB: x 1)
g_4	170 (" ")	170 (" ")
g_4	17 (20 dB: x 10)	17 (0 dB: x 10)

* arbitrary level

Examples for the EK 38

From the value of g_1, a calibrated output of:

1 volt corresponds to $s = -31$ dB m^{-3}

2 volts " " $s = -25$ dB m^{-3}

From the value of g_2 and knowing that $10 \log w = s + g_2$

if $s = -31$ dB m^{-3} then $10 \log w = -3$ and $w = 0.5$ kg m^{-3}

if $s = -25$ dB m^{-3} " $10 \log w = +3$ " $w = 2.0$ kg m^{-3}

From the value of g_4 (for 20 dB: x 10) we see that if the output $\mathcal{E}$ of the integrator is, say, 8 volts for 2 450 transmissions, then

$w_a = (8 \times 17)/2\,450 = 0.055$ kg m^{-2} = 55 tons/km^2 = 190 tons/n.m.^{2}